PROJECT PATHFINDER

CHEMICAL TRANSFER PROPULSION PROJECT PLAN

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PROJECT PLAN

NASA LEWIS RESEARCH CENTER
CLEVELAND, OHIO

SPACE PROPULSION
TECHNOLOGY DIVISION

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PROJECT PLAN

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Technology Division

CHEMICAL TRANSFER PROPULSION

PROJECT PLAN

Prepared by:

11/30/88

Ned P. Hannum
Project Manager
Chemical Transfer Propulsion
Lewis Research Center

Date

Approved by:

11/30/88

Larry A. Diehl, Chief
Space Propulsion Technology Division
Lewis Research Center

Date

Approved by:

J. Stuart Fordyce

11/30/88

J. Stuart Fordyce
Director of Aerospace Technology
Lewis Research Center

Date

Approved by:

12/1/88

Robert L. Zurawski
Program Manager
Chemical Transfer Propulsion
Headquarters

Date

SPACE PROPULSION
TECHNOLOGY DIVISION
LEWIS RESEARCH CENTER

FOREWORD

Pathfinder is a research and technology initiative by the National Aeronautics and Space Administration (NASA) which will strengthen the technology base of the United States civil space program in preparation for future space exploration missions. These missions may include intensive study of the Earth, a return to the Moon, piloted missions to Mars, or the continuing robotic exploration of the Solar System. Pathfinder begins in Fiscal Year 1989, managed by the NASA Office of Aeronautics and Space Technology, to advance a collection of critical technologies for these missions and ensure technology readiness for future national decisions regarding exploration of the solar system. Pathfinder extends the technological foundation being established by the Civil Space Technology Initiative (CSTI), which began in Fiscal Year 1988. While CSTI focuses on advancing a family of technologies for transportation to and operations in near Earth orbit and supporting science activities, Pathfinder looks toward longer-term missions beyond Earth orbit and into the solar system.

Four major thrusts of Pathfinder are: Surface Exploration technology, In-Space Operations technology, Humans-in-Space technology, and Space Transfer technology. The Space Transfer thrust will provide the critical technologies needed for transportation to, and return from, the Moon, Mars, and other planets in the Solar System, as well as for reliable and cost-effective Earth-orbit operations. A key element of this thrust is the Chemical Transfer Propulsion program which will provide the propulsion technology for high performance, liquid oxygen/liquid hydrogen expander cycle engines which may be operated and maintained in space. These advanced engines will enhance or enable a variety of future space exploration missions.

This Project Plan describes the goals and objectives, management plan, technical plan, resources and financial management plan, facilities plans, and technology transfer planning for the Chemical Transfer Propulsion element of Pathfinder.

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SECTION 1.0

EXECUTIVE SUMMARY

1.1 PROGRAM GOALS AND OBJECTIVES

The goal of the Chemical Transfer Propulsion Program is to provide the technology necessary to confidently proceed, in the 1990's, with the development of high performance liquid oxygen/liquid hydrogen expander cycle engines for future space exploration missions. Such advanced chemical rocket engines would enable transportation to, and return from, the Moon, Mars, and other planets in the Solar System, as well as reliable and cost-effective Earth-orbit operations. Propulsion system trade studies, mission-focused technology efforts and engine systems technology efforts will be conducted to evaluate technology readiness and bridge the technology gap between basic research and technology efforts conducted to date and the eventual development of advanced liquid oxygen/liquid hydrogen expander cycle engines for space transfer vehicles.

Major program objectives include the validation of a design and analysis methodology base for liquid oxygen/liquid hydrogen expander cycle engines in a test bed engine system, the demonstration of mission-focused engine components, and the demonstration of the technology base for a new space transfer engine in a focused-technology test bed engine. Key technical issues which will be addressed in the program include: man rating, high performance engine operation, reusability, fault tolerance, deep throttling with minimum performance loss, and design criteria for operation and maintenance of the engine in space (space basing).

1.2 ORGANIZATION AND MANAGEMENT

The Chemical Transfer Propulsion Program is divided into three major research areas: 1) Propulsion Studies, 2) Mission-Focused Technologies and 3) Engine Systems Technology. Drawing on technology from the Propulsion Base R&T Program, advanced liquid oxygen/liquid hydrogen expander cycle engine components will be designed, fabricated and tested in component test stands. The components will be assembled into a test bed engine for proof-of-concept engine system testing. In parallel, propulsion studies will define propulsion system requirements which will guide the selection of advanced mission-focused component technologies. The advanced engine components emerging from mission-focused technology efforts will be integrated into a focused-technology test bed engine. The resulting system will be tested to verify the technology base and to conduct systems research and technology preparatory to, and in parallel with, any resulting new space engine development program.

A Program Manager in the OAST Propulsion, Power, and Energy Division, Code RP, will have program management responsibilities for the Chemical Transfer Propulsion Program which includes establishing, in concert with the Center Project Manager: 1) program planning to establish objectives, scope and overall programmatic approaches, 2) coordination with the Office of Exploration, the Office of Space Flight and organizations external to OAST to assure that future space vehicle requirements guide propulsion technology efforts within the program, and 3) reporting on a regular basis to the Program Manager for Pathfinder as to program status and accomplishments. A Program Plan prepared by the Program Manager will furnish top-level programmatic information and serve as a "contract" between Code RP and OAST senior management. The OAST/SSTAC advisory committee structure will also be used jointly by the Program and Project Manager to provide a more specific and dedicated advisory function to the program.

The NASA Lewis Research Center (LeRC) will be the Lead Center for the Chemical Transfer Propulsion Program. A Project Manager located within a discipline organization at LeRC will be exclusively responsible for the execution of the program. The Project Manager will provide regular integrated assessments of the program (in the form of monthly letters, quarterly MICS, and annual reports) to the OAST-RP Program Manager, who will, in turn, report to the Pathfinder Program Manager. The Project Manager will develop a detailed Project Plan for the Chemical Transfer Propulsion Program. When approved by Headquarters, the Project Plan will serve as the "contract" between LeRC and OAST. The Project Plan, which will be updated annually prior to the start of the fiscal year, will describe the efforts and resources required to fulfill the stated objectives of the program. Regular reviews will be conducted to ensure a planned pace of accomplishment to meet the goals and objectives of the program.

1.3 SCHEDULES AND DELIVERABLES

By the end of 1992, propulsion studies will be complete, generating engine parametric data and propulsion requirements to guide technology efforts in the program. Technology concepts for mission-focused technology efforts will be formulated and proof-of-concept tests of many advanced design concepts and analytical methods will be demonstrated using laboratory and bench rig tests. Testbed engine efforts leading to the validation of the high pressure, high performance liquid oxygen/liquid hydrogen expander engine concept will be well underway. Testing of components for the test bed engines will be nearly complete, leading to validation of engine component design methodologies and analytical models.

By 1998, all critical technologies for an advanced liquid oxygen/liquid hydrogen expander cycle engine will be developed and verified in an integrated, focused-technology test bed. Focused-technology test bed engine testing in a simulated space environment will validate design/analysis methodologies and the technology base for a high performance, space-based, throttleable, reusable liquid oxygen/liquid hydrogen expander cycle engine, including definition of health monitoring and control systems. By 1998, the technology necessary to confidently proceed with the development of an advanced liquid oxygen/liquid hydrogen expander cycle engine to meet future space exploration mission requirements will be available.

1.4 RESOURCES

Projected resources of $76 million through FY93 are required to accomplish the milestones and to provide the deliverables on the specified schedule for the Chemical Transfer Propulsion Program for Fiscal Year 1989 through 1993. Resources approved and allocated for Fiscal Year 1989 total $4.0 million. Funding and workforce requirements for the first five years of the program are summarized in Table V.

SECTION 2.0
INTRODUCTION

2.1 PROJECT PATHFINDER OVERVIEW

American leadership on the space frontier requires aggressive programs in technology development. Technological advance will be critical to programs for future space exploration missions (Ref. 1). These missions may include an intensive study of the Earth, a return to the Moon, piloted missions to Mars, or the continuing robotic exploration of the Solar System (Ref. 2). The technologies needed for success in these ventures are many and varied. The National Aeronautics and Space Administration (NASA), recognizing that it must intensify and broaden the scope of its research and technology program to provide the range of technical options and evaluate technological readiness in select areas to enable future space exploration missions, is initiating Project Pathfinder.

Project Pathfinder is a research and technology initiative which will strengthen the technology base of the United States civil space program in preparation for future space exploration missions. Pathfinder is a long-term program of both research and demonstrations which begins in Fiscal Year 1989. It is managed by the NASA Office of Aeronautics and Space Technology (OAST) and has the goals to to advance a collection of critical technologies for future space missions and to ensure technology readiness for future national decisions regarding exploration of the Solar System (Ref. 3).

Pathfinder is organized into four programmatic thrusts: 1) Surface Exploration, 2) In-Space Operations, 3) Humans-in-Space, and 4) Space Transfer, as shown in Figure 1. The Surface Exploration thrust will provide the critical technologies needed for gathering scientific and engineering data for robotic and piloted missions to the Moon, Mars and other planets in the Solar System. Technologies needed for Earth-orbit staging and operations, as well as planetary operations, will be worked in the In-Space Operations thrust. The Humans-in-Space Thrust will provide technology and understanding needed to ensure safe and productive human space exploration missions. Finally, the Space Transfer thrust will provide critical technology for transportation to, and return from, the Moon, Mars, and other planets in the Solar System, as well as for reliable and cost-effective Earth-orbit operations (Ref 4). Additional information on Project Pathfinder may be found in the Pathfinder Program Plan (Ref. 5).

Chemical Transfer Propulsion is a key element of the Space Transfer thrust and will provide the technology for high-performance, liquid oxygen/liquid hydrogen expander cycle engines for space-based transfer vehicles, as well as for Lunar and Mars landers.

2.2 DOCUMENT PURPOSE AND SCOPE

The purpose of this Project Plan is to:

1. Establish detailed goals and objectives.
2. Specify a detailed work breakdown structure.
3. Define an organization and management structure at Lewis Research Center that will be used in accomplishing the work described within this plan.
4. Define a detailed technical plan that includes objective, approach, scheduled milestones, and deliverable products.
5. Establish the resources required to meet the schedules, milestones, and deliverable products.
6. Establish the requirement for a financial management plan.
7. Establish the requirement for a facility plan.
8. Establish the requirement for a technology transfer plan.

The Project Plan, then, consists of the information on scope, content, and long-range plans of the Chemical Transfer Propulsion Program. The Project Plan and the Program Plan collectively serve as the implementation documents for the program.

The Project Plan is to be updated annually prior to the completion of the fiscal year, or if other occasions should arise necessitating a change in the interim.

SECTION 3.0
CHEMICAL TRANSFER PROPULSION PROGRAM OVERVIEW

3.1 MISSION STUDIES AND TECHNOLOGY REQUIREMENTS

In its report to NASA in 1987, the Committee on Advanced Space Technology of the National Research Council recommended that advanced propulsion technologies for future space missions be afforded the highest priority of R&D activity within NASA. Recognizing that propulsion is a pacing item for future space exploration missions, the committee suggested that NASA pursue a strong program leading to the design and development of reusable cryogenic transfer vehicle engines with features of fault tolerance, high reliability and longevity (Ref. 6). The NASA Office of Aeronautics and Space Technology has responded with the Chemical Transfer Propulsion element of Pathfinder, which will provide the technology necessary to confidently proceed with the development of high performance liquid oxygen/liquid hydrogen expander cycle engines for future space exploration missions, as well as to fulfill the orbit transfer role in the LEO to GEO space.

NASA's planning for future exploration of the Solar System includes unmanned (precursor) and manned missions to Mars and its moons, as well as a resumption of manned missions to the Moon to establish Lunar observatories. A significant portion of the cost for these missions depends on launch vehicle and on-orbit fuel requirements. One of the keys to reducing cost is to minimize the propellant mass in low-Earth orbit required to achieve a transfer trajectory, to accomplish orbit insertion, to effect a planetary landing, and to return to Earth. Launch of the many millions of pounds required for virtually all future space exploration mission scenarios may be affordable only if advanced propulsion systems can be made available (Ref. 6). Reduced propellant requirements in orbit translate to substantial cost savings because fewer Earth-to-orbit vehicle launches are required to accomplish the mission. For example, in the case of a manned Mars mission, an increase of 35 seconds of engine specific impulse saves the cost of at least two Earth-to-orbit vehicle launches. A key enabling technology to greatly reduce in-orbit propellant mass requirements is the development of a high-performance chemical transfer engines.

Another key to reduced cost is to develop of reusable transfer stages that are based in and operated from low-Earth orbit, are operated in LEO to GEO space, and are used in the exploration missions. Technologies that will enable automated in-orbit operation (such as refueling, maintenance, servicing, and preflight systems checkout, as well as fault-tolerant in-flight operation) are critical to the successful development and use of space-based vehicle systems. Integrated controls and health monitoring systems will be required for such fault tolerant engines which will be repeatedly operated and maintained in space.

The NASA Office of Exploration (OEXP) is currently studying several mission scenarios to provide recommendations and alternatives for an early 1990's national decision on a focused program for human exploration of the Solar system. These mission scenarios include human expeditions to the Martian moon Phobos, human expeditions to Mars, human tended Lunar observatories, and an evolutionary expansion from a Lunar outpost to Mars exploration (Ref. 7). A preliminary set of propulsion technology requirements generated by OEXP for these mission scenarios are presented in Table I. Requirements for these propulsion systems include: 1) fault tolerance and high reliability, 2) space basing, long life, and space maintainability, 3) man rating, 4) reusability, restart capability, and checkout before reuse, 5) diagnostic capability (integrated controls and health monitoring), and 6) some level of on-orbit assembly.

3.2 TECHNOLOGY ASSESSMENT

The only upper stage liquid oxygen/liquid hydrogen expander cycle engine currently in operation is the RL10 engine which was developed and certified in the late 1950's and early 1960's. Two RL10A-3-3A engines are used on the expendable Atlas Centaur vehicle. The RL10A-3-3A is a regeneratively cooled, turbopump-fed rocket engine that weighs approximately 310 pounds and produces a rated vacuum thrust of 16,500 pounds (Ref. 8). With a chamber pressure of 465 psia, the engine delivers moderate performance (444.4 seconds specific impulse at mixture ratio of 5:1 using a 61:1 area ratio nozzle),** has limited throttling capability (with significant performance penalties) and no on-board diagnostics. It was designed for and has been used only on expendable vehicles, and is not compatible with future demands for performance, reusability, space-basing, man rating, and fault tolerance.

In the early 1970's, NASA initiated a technology program directed toward an advanced liquid oxygen/liquid hydrogen upper stage engine, as shown in Figure 2. The program initially focused on an advanced space engine utilizing a staged combustion cycle for very high pressure, high performance operation. The Advanced Space Engine technology program was carried through component verification testing, at which time it was decided that a liquid oxygen/liquid hydrogen expander cycle engine would better satisfy future mission requirements. The Orbital Transfer Rocket Engine technology program, which began in the early 1980's, focused on advanced component technologies for high performance (high pressure), reusable liquid oxygen/liquid hydrogen expander cycle engines which would be space based and man-rated. Efforts were focused on technologies for high-speed turbomachinery, high-heat-transfer combustors, large-area-ratio nozzles, and health monitoring systems. The basic proof-of-concept of advanced, high-performance liquid oxygen/liquid hydrogen expander cycle components was only partially demonstrated during this program, which has given way to the Chemical Transfer Propulsion Program. Some limited testing of turbomachinery and health monitoring components (sensors) in a breadboard engine was also conducted.

**Later investments in RL10 technology resulted in modest performance improvements (459.8 seconds specific impulse for the RL10 Derivative IIB at a mixture ratio of 6.0 using a 205:1 area ratio nozzle).

What remains to be accomplished in order to confidently proceed with the development of an advanced high performance liquid oxygen/liquid hydrogen expander cycle engine for future space exploration missions is: 1) the validation testing of engine components, 2) testing of components assembled into an engine system (to study component interactions, system transients, system dynamics, and health monitoring/control systems), and 3) the verification of design and analysis methodologies at both the engine component and engine system level. Pathfinder Chemical Transfer Propulsion is a focused program intended to elevate technology readiness (to Level 6 as shown in Table III) by bridging the technology gap between basic research and technology efforts conducted to date (Level 3) and the eventual development of advanced liquid oxygen/liquid hydrogen engines for space transfer vehicles.

3.3 CHEMICAL TRANSFER PROPULSION PROGRAM GOALS AND OBJECTIVES

The goal of the Chemical Transfer Propulsion Program is to provide the technology necessary to confidently proceed, in the 1990's, with the development of high-performance, liquid oxygen/liquid hydrogen expander cycle engines for future space exploration missions. Major program objectives are:

1. Proof-of-concept demonstration of a high performance, liquid oxygen/liquid hydrogen expander cycle in a test bed engine system, including:
   (a) Validation of high pressure, high performance expander cycles

   (b) Investigation of engine system interactions, transients, dynamics, control functions, and preliminary health monitoring techniques.

2. The validation of a design and analysis methodologies to support the development of future, high performance liquid oxygen/liquid hydrogen expander cycle engines including:

   (a) Assembly and validation of analytical methodologies for the design of advanced liquid oxygen/liquid hydrogen expander cycle engine components and systems

   (b) Validation of design concepts for high performance, space-based, throttleable liquid oxygen/liquid hydrogen expander cycle engines

3. Mission-focused components integrated into a focused-technology test bed engine to demonstrate the high performance, liquid oxygen/liquid hydrogen expander cycle engine system technology that is to be the basis for future space engine development

4. Results of propulsion studies conducted to define firm propulsion requirements and to trade propulsion system performance, configuration, operating characteristics, and the attributes that are key to long-term space transportation infrastructures (space-basing, reuse, man-rating, fault tolerance).

3.4 TECHNICAL APPROACH

At the present time, future space exploration mission scenarios have not been defined to a point where firm propulsion requirements exist. However, technology goals for an advanced liquid oxygen/liquid hydrogen space engine which support the range of future mission options are presented in Table II. The major technical issues for an advanced liquid oxygen/liquid hydrogen expander cycle engine which will be addressed in the Chemical Transfer Propulsion Program are:

1. High performance:

   High performance engine operation (Goal of 490 lbf-sec/lbm vacuum specific impulse)

2. Deep throttling:

   Continuous and stable engine operation from rated thrust to perhaps 5% (20:1 vacuum thrust throttling ratio) with minimum performance loss

3. Reusability:

   Specifications of the number of starts and the number of hours of operational life, as well as the number of starts and hours of service-free life are to be established. Preliminary assessments are: 500 starts/20 hours operational life, 100 starts/4 hours service free life.

4. Space Basing:

   Modular engine design for space maintenance, operating characteristics and diagnostics and techniques that facilitate long-term storage and operations in space.

5. Fault tolerance:

   Fault tolerance in the "classical" sense: the propulsion system shall tolerate a given number of failures without causing a hazard, or fail operational/fail safe. As an additional requirement, the system shall tolerate off-design operation of some combinations of components in a way that maintains system durability to allow completion of the mission.

6. Man rating

   High reliability; redundancy of all critical systems; design and operational safety; proven design standards; enable safe haven or return.

The technical approach to be used in the Chemical Transfer Propulsion Program is summarized in Figure 3. The program consists of propulsion studies, focused advanced component technology efforts, and systems technology activities. Drawing on technology developed in the Orbital Transfer Rocket Engine Technology program, advanced liquid oxygen/liquid hydrogen expander cycle engine components will be designed, fabricated and tested in component test stands. The components will then be assembled into a test bed engine for systems testing. In parallel with these activities, propulsion studies will be conducted to define propulsion system requirements which will guide the selection of focused advanced component technologies to be pursued in the program. The focused advanced engine components emerging from these efforts will be integrated into a focused-technology test bed engine. This engine system will be tested to complete Level 6 of technology readiness.

SECTION 4.0
MANAGEMENT PLAN

4.1 OVERVIEW

The Chemical Transfer Propulsion Program is a focused technology program leading to technology demonstrations of an advanced liquid oxygen/liquid hydrogen expander cycle engine system and engine components. The extensive variety of work being performed in the program requires a management approach which is tailored to coordinating and integrating the various work activities. The management system must ensure achievement of planned accomplishments, effective reporting and control, and permit prompt replanning if required. The work breakdown structure, management structure, program coordination, planning and documentation, reporting, and advisory groups for the Chemical Transfer Propulsion Program are described in this section.

4.2 WORK BREAKDOWN STRUCTURE

The Chemical Transfer Propulsion Program is divided into three major research areas which allows work to be focused in critical areas and provides a flow mechanism for raising the technology to higher levels of hardware definition, leading to the eventual testing of an advanced liquid oxygen/liquid hydrogen expander cycle focused-technology test bed engine in the late 1990's. The major work packages are; (1) Propulsion Studies (3) Mission-Focused Technologies and (3) Engine Systems Technologies. Figure 4 illustrates the top-level work breakdown structure elements. The work flows from one element to the succeeding one. The propulsion studies will generate propulsion requirements to guide the selection of mission-focused technologies. Advanced engine subcomponents and components emerging from the mission-focused technology efforts will be tested in an engine system in the focused-technology test bed.

4.3 ORGANIZATION AND MANAGEMENT STRUCTURE

Program management responsibilities for the Chemical Transfer Propulsion Program will reside in OAST's Propulsion, Power and Energy Division, Code RP. A Program Manager in Code RP will establish overall programmatic goals and objectives and serve as the focal point at NASA Headquarters for the Chemical Transfer Propulsion Program. The Chemical Transfer Propulsion Program Manager will report on regular basis to the Program Manager for Pathfinder as to the status, problems and accomplishments of the program.

The NASA Lewis Research Center (LeRC) will be the Lead Center for the Chemical Transfer Propulsion Program. As the Lead Center, LeRC will assume full responsibility of achieving the goals and objectives of the program, as well as for integrating next-tier assignments in the program both within LeRC and at participating Centers. LeRC is the only Participating Center in the Chemical Transfer Propulsion Program at the present time. The Marshall Space Flight Center (MSFC) is included in the management structure for the program in Figure 5. MSFC is presently funded by the NASA Office of Space Flight (Code MD) to conduct studies for an advanced space transfer vehicle and may become involved in the program in later stages of technology development. At the present time, only coordination will be required to ensure that efforts within the Chemical Transfer Propulsion Program are guided by requirements generated from these vehicle studies.

The Lewis Research Center will plan and integrate Chemical Transfer Propulsion activities and execute some portion of that plan within the Center. A Project Manager located at LeRC will be the focal point of all field installation activity bearing directly on the Chemical Transfer Propulsion Program and will be exclusively responsible for the execution of the program within guidelines and controls prescribed by NASA Headquarters and LeRC management. In essence, the Project Manager will be responsible for the day-to-day supervision and the execution of the program as carried out by industrial contractors, field installation personnel, and university participants. These responsibilities include: 1) technical planning, 2) maintaining and reporting schedules, 3) planning, disbursement and tracking of resources, and 4) facility planning as required. Using inputs from all involved organizations, and especially Project Managers for propulsion studies, mission-focused technologies, and engine systems technologies, the LeRC Project Manager will provide regular integrated assessment of project status to the Chemical Transfer Propulsion Program Manager.

The Chemical Transfer Propulsion Management Structure is depicted in Figure 5.

4.4 PROGRAM COORDINATION

Through the Chemical Transfer Propulsion Program Manager in Code RP, the LeRC Project Manager will be kept informed and coordinated with the Office of Exploration (OEXP), Code Z, and the Office of Space Flight (OSF), Code MD, to assure that future space vehicle requirements guide propulsion technology efforts within the Chemical Transfer Propulsion Program. OEXP will define scenarios for future, human exploration missions in the Solar System. OSF will establish space vehicle requirements for these future space exploration missions, which will guide the development of propulsion technologies. Mission and vehicle definition will be important in determining propulsion system characteristics such as; (1) minimum performance requirements, (2) thrust level, (3) throttling requirements, (4) life, reliability and reusability requirements and (5) design criteria for in-space engine operation and maintenance. Coordination with OSF will become particularly important in later stages of technology development to facilitate technology transfer and adoption in advanced development programs.

Within OAST, coordination will be maintained with the propulsion R&T Base program, as applicable to chemical transfer propulsion technologies. External to OAST, coordination will also be maintained with the Department of Defense through the Joint Army, Navy, NASA, Air Force (JANNAF) Interagency Propulsion Committee and the NASA/AF Space Technology Interdependency Group (STIG) for the exchange of information and technology where propulsion technologies and application are common.

4.5 PROGRAM PLANNING AND DOCUMENTATION

A detailed five-year plan, with less detailed planning to ten years, will be developed prior to implementation of the Chemical Transfer Propulsion Program. This plan will be documented in a top-level Program Plan and a detailed Project Plan for the Chemical Transfer Propulsion Program. The Program Plan will be developed by the OAST Chemical Transfer Propulsion Program Manager and will describe the overall goals and objectives.

The LeRC Project Manager will be responsible for developing a detailed Project Plan for the Chemical Transfer Propulsion Program. The Project Plan will describe technical content, Center responsibilities, resource allocations, milestones and deliverables for the Chemical Transfer Propulsion Program. It will provide the structure of planned accomplishments which will serve as a basis to assess and monitor the program. In essence, the Project Plan will serve as a "contract" between LeRC and the OAST Propulsion, Power and Energy Division, Code RP, such that Headquarters is obligated to provide resources while LeRC is required to execute the work to fulfill the stated objectives of the program. The Project Plan will be updated on an annual basis to reflect changes and content as appropriate and will be submitted to NASA Headquarters for approval approximately one month prior to the end of each fiscal year.

The Research and Technology Objectives and Plans (RTOP) will continue to be used as a document in OAST's management system for R&T programs. However, for Pathfinder programs, the Project Plan will serve as a basis for communication and negotiation between Headquarters and the performing Field Center, and when approved annually by Headquarters, will become the contract between these organizations. So as to avoid duplication of effort, a RTOP that references the Project Plan will be used.

4.6 PROGRAM REVIEWS

Formal reviews of the Chemical Transfer Propulsion Program will be conducted semi-annually; mid-way during, and near the end of, each Fiscal Year. The focus of the mid-fiscal year review will be on program content, status and progress versus the Project Plan. Test results, experimental and analytical data, and program accomplishments will be central to this review. The review will include an advisory committee for the Chemical Transfer Propulsion Program and principal managers and technical specialists directly involved in the program from Headquarters (RP Program Manager), the Lead Center (the Project Manager), participating Centers, contractors and universities.

The purpose of the review near the end of the fiscal year will be for OAST to evaluate the specific Project Plan against schedule, accomplishments and resources. During this formal review, each Participating Center will represent their area of expertise and responsibility. The Lead Center will be responsible for making an integrated assessment of progress and accomplishments versus the Project Plan.

Special, detailed technical reviews will also be conducted as necessary to ensure a planned pace of accomplishment to meet the goals and objectives of the program and to expose any problems or potential malfunctions before committing the program to the next step. These special reviews will include:

1. Review of design and analysis methodologies for liquid oxygen/liquid hydrogen expander cycle engine components/systems.
2. Preliminary and critical design reviews for the test bed engine
3. Propulsion system trade studies
4. Technology reviews for advanced (mission-focused) engine components (prior to their integration into the focused-technology test bed)
5. Engine systems technology review (prior to integration of the test bed engine system into the focused-technology test bed)

Additionally, there will be special technical reviews scheduled and implemented by the LeRC Project Manager.

4.7 PROGRAM REPORTING

Program Reporting is illustrated in Figure 6.

4.7.1 MONTHLY REPORTING

Monthly reporting for the Chemical Transfer Propulsion Program will be accomplished on a memorandum basis to the OAST-RP Program Manager. The specific content and format of the monthly report will be determined jointly by the LeRC Project Manager and the OAST-RP Program Manager. Along with this monthly memorandum, the LeRC Project Manager will submit to the OAST-RP Program Manager a set of briefing charts which contain a concise, top-level overview of the program and describe program status, issues and highlights/accomplishments for the reporting month.

4.7.2 QUARTERLY REPORTING

The LeRC Project Manager will be responsible for preparing formal quarterly reports on the Chemical Transfer Propulsion Program for submission to the OAST-RP Program Manager by the middle of the month after the end of the preceding quarter. The tentative schedule for the quarterly reports will be:

First Quarter (Oct. 1 through Dec. 31)	Jan. 15 Report Due
Second Quarter (Jan 1 through Mar. 31)	April 15 Report Due
Third Quarter (Apr. 1 through June 30)	July 15 Report Due
Fourth Quarter (July 1 through Sept. 30)	Oct. 15 Report Due

The Management Information and Control System (MICS) will be the format for the quarterly reports to OAST. This reporting system summarizes technical, managerial, and financial status; problems; and prospects, compared to the Project Plan baseline. Project schedule, progress and resources expended against total allocated resources will be reported for the overall project (and for each Center as other Centers become involved). If participating Centers (other than LeRC) become involved, each will be responsible for reporting the required information through the Project Manager. Specific control, level of reporting (WBS level), etc. will be determined by the OAST-RP Program Manager and the Pathfinder Program Manager.

4.7.3 ANNUAL REPORTING

There will be no formal requirements for a separate annual report for the Chemical Transfer Propulsion Program. However, one of the four quarterly reports for each year will be augmented (per future instruction) to provide an annual report as well as a report for that quarter. This annual report will be provided to the OAST-RP Program Manager by the LeRC Project Manager.

4.7.4 SPECIAL REPORTS

The LeRC Project Manager will provide for the appropriate distribution specialtechnical reports, plans and materials documenting contractor, university and in-house research efforts conducted in the Chemical Transfer Propulsion Program. Distribution will include, as appropriate, principal managers and technical specialists directly involved in the program from NASA Headquarters, participating Centers, contractors and universities, as well as personnel from other Government agencies where similar propulsion technologies and applications are being pursued.

Informal telecons and face-to-face meetings between the program and project management for the Chemical Transfer Propulsion Program will also be conducted to communicate data, problems and recommendations in a timely fashion.

4.8 ADVISORY COMMITTEES

The OAST Space Systems Technology Advisory Committee (SSTAC) and the Aerospace Research and Technology Subcommittee (ARTS) will be utilized for the Chemical Transfer Propulsion Program. These advisory groups will provide top-level programmatic and technical guidance to the program. In addition, a Space Propulsion Advisory Committee will be assembled to provide a more specific advisory function to the Chemical Transfer Propulsion Program. This committee composed of principal managers and technical specialists from NASA, other government agencies, industry and academe and will provide specific programmatic and technical guidance to the program once each year at the mid-Fiscal Year annual review. The LeRC Project Manager will propose, assemble, and determine the specific charter of the Space Propulsion Advisory Committee.

SECTION 5.0

TECHNICAL PLAN

5.1 TECHNICAL OVERVIEW

The Chemical Transfer Propulsion Program will evolve fundamental liquid oxygen/liquid hydrogen expander cycle propulsion technologies through component, subsystem and system hardware demonstrations. Work in the Base R&T program over the past several years has been directed towards establishing engine design concepts capable of meeting expected mission requirements and pursuing critical technology advances necessary to achieve performance, life and operational goals. Advanced design concepts and analytical methods have also been developed using laboratory and specially designed test equipment.

The Chemical Transfer Propulsion Program will build on the R&T Base by moving progressively through full-scale component, subsystem, and system level validations and demonstrations. The program will consist of three phases. Phase I will be directed toward advanced design and analysis methodology development. Highly instrumented engine components capable of operating over a wide range of conditions will be designed, fabricated and tested. This phase of the program will be completed in FY1992. In Phase II the demonstrated components and subsystems from Phase I will be assembled into an engine system to conduct component interaction and system level verification testing. Engine models developed to predict transient, steady state and throttling performance will be developed verified and refined. The output of this phase of the program will be the validation of high performance liquid oxygen/liquid hydrogen expander cycle engine and the investigation of engine system interactions and characteristics. Engine system issues such as deep throttling, control functions, and health monitoring techniques will be investigated. Phase II will be completed in FY1994. The third phase of the program will be directed toward the final program objective of demonstrating the performance, life and operation of a flight-type liquid oxygen/liquid hydrogen expander cycle engine designed for the requirements of future space exploration missions.

These three phases of the Chemical Transfer Propulsion Program will be conducted with three integrated work package elements.

Propulsion studies, mission focused technology efforts, and engine system technology efforts will be conducted, leading to the testing of a high performance liquid oxygen/liquid hydrogen expander cycle engine with mission focus. The objectives and overall technical approach for each of these three WBS work elements are described in the following sections.

5.1.1 PROGRAM ELEMENTS

5.1.1.1 PROPULSION STUDIES

The objectives of the propulsion studies are to provide engine parametric data to support ongoing mission/vehicle studies and to optimize engine components and systems to satisfy the propulsion system requirements resulting from these studies. Study results will guide subcomponent and component efforts to be conducted in the Mission-Focused Technologies area.

5.1.1.2 MISSION-FOCUSED TECHNOLOGIES

The objectives of mission-focused technology efforts are to formulate concepts and develop advanced liquid oxygen/liquid hydrogen expander cycle engine subcomponents and components which satisfy mission requirements. Propulsion requirements for deep throttling, life, reusability, performance, and in-space operation and maintenance will drive the selection of technologies to be pursued. Advanced design concepts and analytical methods will be developed and demonstrated utilizing laboratory, bench, and rig testing. In promising areas, advanced design components will be fabricated for demonstration testing in the test bed engine.

5.1.1.3 ENGINE SYSTEM TECHNOLOGY

The engine system technology effort will also be phased. The first phase will be a 1989-technology test bed engine. Liquid oxygen/liquid hydrogen expander cycle engine components will be designed and fabricated using 1989 technology and design/analysis methodologies. These components will be tested to verify the analytical methods, validate performance, and then assembled into a test bed engine.

The test bed engine will be acceptance tested and then delivered to NASA LeRC. At LeRC, the engine will be tested to:

1. Validate the high pressure, high performance expander cycle concept at the engine system level.

2. Investigate system interaction, transient, and dynamic effects which will influence component development in the mission-focused technologies work element.

3. Investigate control functions and health monitoring techniques.

4. Verify the steady-state and dynamic engine system computer codes of the test bed engine developed under contract.

5. Verify engine system design and analysis methodologies used in the design of the test bed engine.

In the second phase of the engine systems technology, mission-focused components emerging from the mission-focused technologies work element will be integrated into the test bed engine. The test bed engine will thus evolve into the focused-technology test bed engine. Testing of the focused-technology test bed engine in a simulated environment will achieve the program goal of demonstrating the technology base for future space engines.

5.1.2 SUMMARY OF DELIVERABLES

For Pathfinder, 1992 is a milestone when a National decision and commitment is to be made regarding exploration of the Solar System. For missions occurring early in the twenty-first century, development programs must be initiated late in the 1990's (circa 1998). Therefore, it is important to quantify and plan for deliverables from Pathfinder programs for both 1992 and 1998; with 1992 being a "window of knowledge" when an assessment of technology status will occur and 1998 being a time of technological readiness to confidently proceed with development programs in relevant areas. In this Section, 1992 deliverables, 1998 deliverables, and technology readiness objectives for the Chemical Transfer Propulsion Program are specified.

5.1.2.1 1992 DELIVERABLES

By the end of 1992, engine parametric data packages and propulsion trade studies will be complete. Propulsion system requirements to guide technology efforts in the program will be defined from mission, vehicle and propulsion studies. Technology concepts and applications for advanced, mission-focused engine subcomponents and components will be formulated. Advanced design concepts and analytical methods will be developed using laboratory bench and rig tests. Design criteria for in-space engine operation and maintenance will be defined leading to strong programs directed at health monitoring, control systems, fault-tolerant engine operations, and automated pre-flight checkout, as well as modular engine design for in-space change-out. Test bed engine contracts for a high pressure/high performance liquid oxygen/liquid hydrogen expander cycle engine will be well underway. Testing of components for the test bed engines will be nearly complete leading to verification of engine component design methodologies and analysis models.

5.1.2.2 1998 DELIVERABLES

By 1998, test bed engine tests will have validated the high performance liquid oxygen/liquid hydrogen expander cycle engine concept. Engine tests will have investigated system interactions, transients, dynamics, control functions and health monitoring techniques, as well as testing of advanced engine components. Verification of component and system design/analysis methodologies will have been completed. A focused-technology test bed will be assembled with components from the Mission-Focused Technology work element. Engine testing in a simulated environment will validate a technology base for a high performance, space-based, throttleable liquid oxygen/liquid hydrogen expander cycle engine, including definition of health monitoring and control systems. By 1998, the technology necessary to confidently proceed (in terms of technical, cost, and schedule risks) with the development of an engine for future space exploration missions will be available.

5.1.3 TECHNOLOGY READINESS OBJECTIVES

The technology readiness level of the liquid oxygen/liquid hydrogen expander cycle engine, as the Chemical Transfer Propulsion Program is initiated in Fiscal Year 1989, can be considered Level 3, as shown in Table III. Key components and related component analytical models for high performance liquid oxygen/liquid hydrogen expander cycle engines, such as pumps, turbines, thrust chambers and health monitoring devices, have been designed, fabricated and tested for proof-of-concept in the Base R&T program over the past several years. With this as a starting point, the Chemical Transfer Propulsion Program will design, fabricate, and test components based on these proof-of-concept designs. These components will be tested in component test stands to determine expected performance and validate analysis and design methodologies.

As the technology readiness will be elevated to Level 4, the components will be integrated into a test bed engine for system characterization testing. Advanced engine components emerging from the Mission-Focused Technology work element will be integrated with the test bed engine to form a focused-technology test bed and elevate technology readiness to Level 5. System validation of hardware and analysis concepts will be conducted in the focused-technology test bed in a simulated space environment to complete Level 6 of technology readiness. At this point in the program, in the late 1990's, the goals and objectives of the Chemical Transfer Propulsion Program will be met. Validated hardware and design methodologies will be available to the development program.

5.2 PROPULSION STUDIES

5.2.1 OBJECTIVES

Propulsion system studies will be conducted in the Chemical Transfer Propulsion Program to provide engine parametric data to support the mission/vehicle studies being conducted by the Office of Exploration (Code Z) and the Office of Space Flight (Code M). The studies will also identify and assess the technology requirements of candidate propulsion systems resulting from the vehicle studies.

5.2.2 TECHNICAL APPROACH

The technical approach for this Work Package is shown in Figure 7. The initial propulsion system parametric data packages needed for the mission/vehicle studies will be generated as a task under the existing OTV Rocket Engine Technology contracts with Aerojet TechSystems Company, Pratt & Whitney, and Rocketdyne. These data packages will be provided to the Code Z and Code M contractors. Provisions will be made to enable close coordination between vehicle and engine study contractors such that the impact of vehicle derived requirements on the engine system can be assessed and the results utilized in the vehicle trade studies.

Once propulsion system requirements have been defined, mission-focused propulsion system studies will be conducted to optimize the engine components and/or systems to satisfy the vehicle requirements. These inputs will be used to guide the Work Package No. 2, Mission-Focused Technologies, activities.

5.2.3 SCHEDULE OF MILESTONES AND DELIVERABLES

The milestones for this Work Package are to support in a timely manner the mission/vehicle studies by Code Z and Code M and to implement in a timely manner the results of the mission vehicle studies into the Chemical Transfer Propulsion Program.

Deliverables are:

1.	Engine parametric data packages	FY89
2.	Special engine parametric data packages	FY90
3.	Mission-focused engine component requirements	FY92
4.	Propulsion trade studies	FY92

5.3 MISSION-FOCUSED TECHNOLOGIES

5.3.1 OBJECTIVE

The objective of Work Package No. 2, Mission Focused Technologies, is to provide mission-specific technology for inclusion into the Focused-Technology Test Bed engine that is scheduled for 1994. This technology will complement the results of the earlier engine technology from the OTV effort.
The Mission-Focused Technologies will include those issues that have not yet been defined; but are size, mission, and cycle specific. These issues are not being covered in the early engine technology effort but will be defined as a result of ongoing propulsion studies in Work Package No. 1.

5.3.2 TECHNICAL APPROACH

The Work Breakdown Structure for this Work Package is shown in Figure 8. The technical approach will be to define those technology issues that are parochial to a space-based, man-rated, reusable, fault-tolerant, liquid oxygen/liquid hydrogen expander-cycle engine that will be used for future space exploration. One aspect of definition will come from the propulsion studies of Work Package No. 1. They will be the thrust level, throttleability range, mixture-ratio range, and size envelope. Where these aspects can not be defined, a broad range of values will be pursued. Up-dating of the configuration and cycle candidates will also be results of the propulsion studies of Work Package No. 1. With this narrowing of configurations, the technology issues parochial to these configurations will be identified.

Once identified, these technology issues will be pursued both as individual components, and as sub-systems in a series of proof-of-concept tasks (Level 3). These tasks would lead next to the component validation work at level 4, and ultimately to the test bed engine demonstration work at level 5.

5.3.3 SCHEDULE OF MILESTONES AND DELIVERABLES

The key milestone for this work package is to provide demonstrated mission focused components for the build-up of the focused-technology test bed engine in FY94. A supplementary milestone is to have all of the mission-focused components available and characterized by FY 97.

In order to meet these goals, several intermediate milestones can be listed. One is to have proof-of-concept validated mission-focused components (Level 3) completed in FY 92. To accomplish this, work on the mission-focused components must start in FY 89.

5.4 ENGINE SYSTEMS TECHNOLOGY

5.4.1 OBJECTIVES

The objectives of this work package element are: 1) validation of the high pressure, high performance expander cycle concept at the engine system level, 2) verification of the 1989 state-of-the-art methodologies for design and analysis of high pressure, high performance expander cycle components and engine system, 3) investigation of system effects on component design, control functions, and health monitoring techniques, and 4) demonstration of advanced, mission-focused components in a focused-technology test bed engine. The testing of the focused-technology test bed engine in a simulated environment will be the demonstration of the chemical transfer propulsion technology base for future space exploration missions.

5.4.2 TECHNICAL APPROACH

The Engine Systems Technology will consist of a contract effort and an in-house NASA LeRC effort. The Work Breakdown Structure is shown in Figure 9.

Using the technology developed in the R&T Base in the 1980's, a contractor will design, fabricate, acceptance test, and deliver to NASA LeRC an advanced, high pressure, high performance expander cycle test bed engine. The test bed engine design will utilize the state-of-the-art design and analysis methodologies available. These methodologies will be verified during the contractor's testing of engine components and during the NASA LeRC in-house test bed engine test program.

The NASA LeRC in-house effort will be an extensive test program of the test bed engine to:

1. Validate the high pressure, high performance expander cycle concept at the engine system level.

2. Investigate engine system interactions, transients, and dynamics and what effect they have on mission-focused component designs.

3. Investigate engine control functions and health monitoring techniques to help direct the mission-focused technology efforts.

4. Verify engine system design and analysis methodologies.

As advanced components emerge from the Mission-Focused Technologies efforts of Work Package No. 2, they will be integrated into the test bed engine for system level testing. In this manner, the 1989-technology test bed engine will evolve into a focused-technology test bed engine in the 1994-1996 time period.

5.4.3 SCHEDULES OF MILESTONES AND DELIVERABLES

The schedule of milestones are:

1.	Issue Test Bed RFP	Feb 89
2.	Select Test Bed Source	Jun 89
3.	Award Test Bed Contract	Sep 89
4.	Establish Test Bed Design & Analysis methodologies	Jan 90
5.	Preliminary Design Review for Test Bed	Apr 90
6.	Methodologies Verification Plan	Aug 90
7.	Final Design Review for Test Bed	Oct 90
8.	Initiate Test Bed Fabrication	Nov 90
9.	Initiate Subcomponent Verification Tests	Jan 91
10.	Initiate Component Testing	Sep 91
11.	Initiate Test Bed Assembly	Apr 92

12.	Complete Test Bed Acceptance	Sep 92
13.	Start LeRC Test Bed Testing	Jan 93

Deliverables are:

1.	Test Bed Contract Work Plan	Dec 89
2.	Test Bed Contract Product Assurance Plan	Dec 89
3.	Test Bed Contract Technical Progress and Financial Management Reports	Monthly
4.	Test Bed Contract Test Plan, Test Reports, Topical Reports	As Required
5.	Test Preliminary Design Report	Jun 90
6.	Methodology Verification Plan	Aug 90
7.	Test Bed Final Design Review Report	Dec 90
8.	Test Bed Computer Codes	Dec 90
9.	Test Bed Engine	Sep 92

SECTION 6.0

RESOURCE AND FINANCIAL MANAGEMENT PLAN

6.1 FIVE YEAR FUNDING REQUIREMENTS

The project described in this Project Plan is longer than five years. However, projected funding requirements to accomplish the milestones and to provide deliverables noted in Section 5.0 for the five year period of Fiscal 1989 through 1993 are approximately $76 million. Pathfinder Funding approved and allocated to the Chemical Transfer Propulsion program for fiscal 1989 totals $4.0 million. Funding required for the first five years of the Chemical Transfer Propulsion Program is summarized in Table V.

6.2 FIVE YEAR WORK FORCE REQUIREMENTS

Table V provides the estimated Civil Service personnel requirements of the first five years of the program. Support service contractor personnel required to augment civil servant resources are not included in these estimates.

6.3 LONGER-RANGE WORK FORCE REQUIREMENTS

Current plans place testing of the focused-technology test bed engine at a Government test facility. Efforts to assemble the test bed would begin in Fiscal Year 1994, so the work force requirements for this activity are not reflected in Table V. In Fiscal Year 1989, the lead Center will prepare (specific content per future discussion and agreement) an Institutional Resources Assessment for the program which will address (civil servant and on-site service contractor) work force requirements and recommend a test facility for conducting the focused technology test bed test program. The assessment will be submitted to the OAST-RP Program Manager by the end of FY 89.

6.4 CONTRACTING PLANS

Contracted efforts in support of the Chemical Transfer Propulsion Program will include industry and universities, as appropriate, (as well as potential involvement through the Small Business Innovative Research (SBIR) Program) to provide needed capabilities not within the current or planned future expertise of the agency. Efforts provided under contract to NASA will include such services as research and technology development tasks in specific areas defined by NASA, support service contracts of a technical or administrative nature, and other services as appropriate.

6.4.1 INDUSTRY

The expertise of the aerospace industry will be extensively utilized in each of the three work package elements of the Chemical Transfer Propulsion

Program. Industry will participate in the Propulsion Studies to provide engine parametric data which will supply definition for future technology efforts within the program. A number of contracts with industry will be initiated in the Mission-Focused Technologies area, addressing various advanced focused technologies. In the Engine Systems Technology area, it is NASA's desire to have multiple contractors involved in the design, fabrication, and testing of test bed engine hardware and in the verification of relevant design methodologies and analytical models for advanced liquid oxygen/liquid hydrogen expander cycle rocket engine components. At the Governments option, industry may conduct test programs with the test bed engine at industrial facilities. For the focused-technology testbed, industry will provide the focused-technology components, subsystems, and systems.

6.4.2 UNIVERSITIES

Another means of accomplishing basic research and technology in support of the Chemical Transfer Propulsion Program is through the use of university grants in areas which have been proposed by the academic community. Universities will be encouraged to participate in the Mission-Focused Technologies area to formulate advanced concepts. Regular review of NASA-funded grants in support of the Chemical Transfer Propulsion Program will be held to highlight academic research and promote a free exchange of technology ideas among the propulsion community.

SECTION 7.0

FACILITIES PLANS

7.1 OVERVIEW

Existing contractor and Government facilities (manufacturing, assembly, component testing, and engine testing) will be utilized. Some facility modifications and/or reactivation may be required, but no new facilities are envisioned at this time.

7.2 LABORATORIES AND COMPUTING

Existing state-of-the-art contractor and Government laboratories and computing facilities will be utilized. Laboratory facilities at Lewis will support materials testing, specialized fabrication techniques, and other capabilities required to produce and evaluate test hardware and materials. Computing facilities at Lewis will be used to support engine system simulations and designs of engine subcomponents, components, and engine systems.

7.3 DEMONSTRATION FACILITIES AND TESTING

For most demonstration testing, existing contractor and Government facilities are adequate. For in-house testing of focused-technology subcomponents and components, Lewis's capability includes:

1. Rocket Engine Test Facility (RETF)
   - Combustion devices hot firing ("A" and "B" stands)
   - Turbomachinery and elements ("C" stand)

2. Fracture Mechanics Laboratory (FML)
   - Turbomachinery bearings (Cells 1, 2, and 5)

3. Combustion Research Laboratory (CRL)
   - Combustion devices, elements

Current engine contractors have similar or comparable facilities.

For demonstration testing of the focused-technology test bed engine (including deep-throttling and a large area-ratio nozzle), a specialized, vacuum rocket engine test stand will be required. The use of a Government facility is anticipated. Several Government facilities have the required vacuum capabilities, including:

1. B-2 Test Stand at Plum Brook Station, NASA Lewis Research Center

2. J-3 Test Stand at Arnold Engineering Development Center, Tullahoma, TN

3. 401 Test Stand at NASA White Sands Test Facility, White Sands, NM

Both B-2 and WSTF 401 require facility upgrades to reach operational status. The need for vacuum capability for the initial test bed engine is not known at this time.

7.4 FACILITIES ASSESSMENT

Existing contractor and Government facilities, with some modifications and/or reactivation, appear at this time to be sufficient for the Chemical Transfer Propulsion Program. However, it is not clear at this time which Government facility is best suited and whether institutional constraints will permit these test programs to be conducted at a given Government facility. Therefore, in FY 1989, LeRC will conduct an overall "Institutional Resources Assessment for the Chemical Transfer Propulsion Program". This assessment will be submitted to the OAST-RP Program Manager by the end of FY 1989. Its purpose will be to: 1) specifically identify the capabilities of, and the demands on, existing propulsion test facilities and the resources (personnel and dollars) needed order to support facility upgrade and the required testing, and 2) define, plan, and budget any anticipated Construction of Facilities (COF) for early support in the program schedule.

SECTION 8.0

TECHNOLOGY TRANSFER PLAN

The effective transfer of propulsion technologies from the research Center to the development Center where the technology will eventually be developed into operational systems for future space transfer missions is recognized as a major goal of the Chemical Transfer Propulsion Program. Planning for the transition of Chemical Transfer Propulsion technology to advanced development in preparation for implementation involves both Headquarters and the Field Center.

At Headquarters, it is critical that the OAST-RP Program Manager develop a constructive, collaborative and supportive relationship with the Advanced Program Development organization (Code MD) such that they may shape the technology program content, monitor progress and facilitate transfer and adoption of technology from the program. The Program Plan and Project Plan for the Chemical Transfer Propulsion Program will be transmitted to Code MD (annually, as they are updated) so that they may have the opportunity to shape the content of the program. In addition, the OAST-RP Program Manager will allow for ongoing insight into technology development in the Chemical Transfer Propulsion Program through Code MD participation in meetings and briefings, as appropriate.

In addition, it is vital to provide development Center participation in the Chemical Transfer Propulsion Program in later stages of technology development. This is a primary reason for including the Marshall Space Flight Center in the program management structure of Figure 5. Either the Lewis Research Center or the Marshall Space Flight Center would be the developer of an advanced liquid oxygen/liquid hydrogen expander cycle engine for future space exploration missions. In Fiscal Year 1989, the LeRC Project Manager will be responsible for developing a formal Technology Transfer Plan which will identify mechanisms for the implementation of technology transfer within NASA and among industry, universities and other Government agencies as appropriate.

9.0 REFERENCES

1. Pioneering the Space Frontier: The Report of the National Commission on Space; National Commission on Space (NCOS); (New York: Bantam Books). 1986.

2. Leadership and America's Future in Space. A Report to the Administrator; Ride, S. K.; (Washington, D.C.; NASA). August 1987.

3. Project Pathfinder: Technology Benefits Assessment. OAST. November 1987.

4. Project Pathfinder: Research and Technology to Enable Future Space Missions. OAST; (Washington, D.C.: Brochure/JPL 400-330). December 1987.

5. Technology for Future NASA Missions: Civil Space Technology Initiative (CSTI) and Pathfinder. Proceedings of a Joint AIAA/NASA Conference held in Washington, D.C.; September 12-13, 1988. NASA Conference Publication 3016. 1988.

6. Space Technology to Meet Future Needs. National Research Council. National Academy Press. Washington, D.C. 1987.

7. Prerequisite Requirements for Exploration Class Missions. Version 2.1. NASA Office of Exploration Document No. Z-MAS-PRD-003. (Washington, D.C.: NASA). May 1988.

8. RL-10 Liquid Rocket Engine Service Manual: Model RL10-10A-3-3A. United Technologies; Pratt & Whitney Aircraft Group. February 15, 1982.

10.0 FIGURES

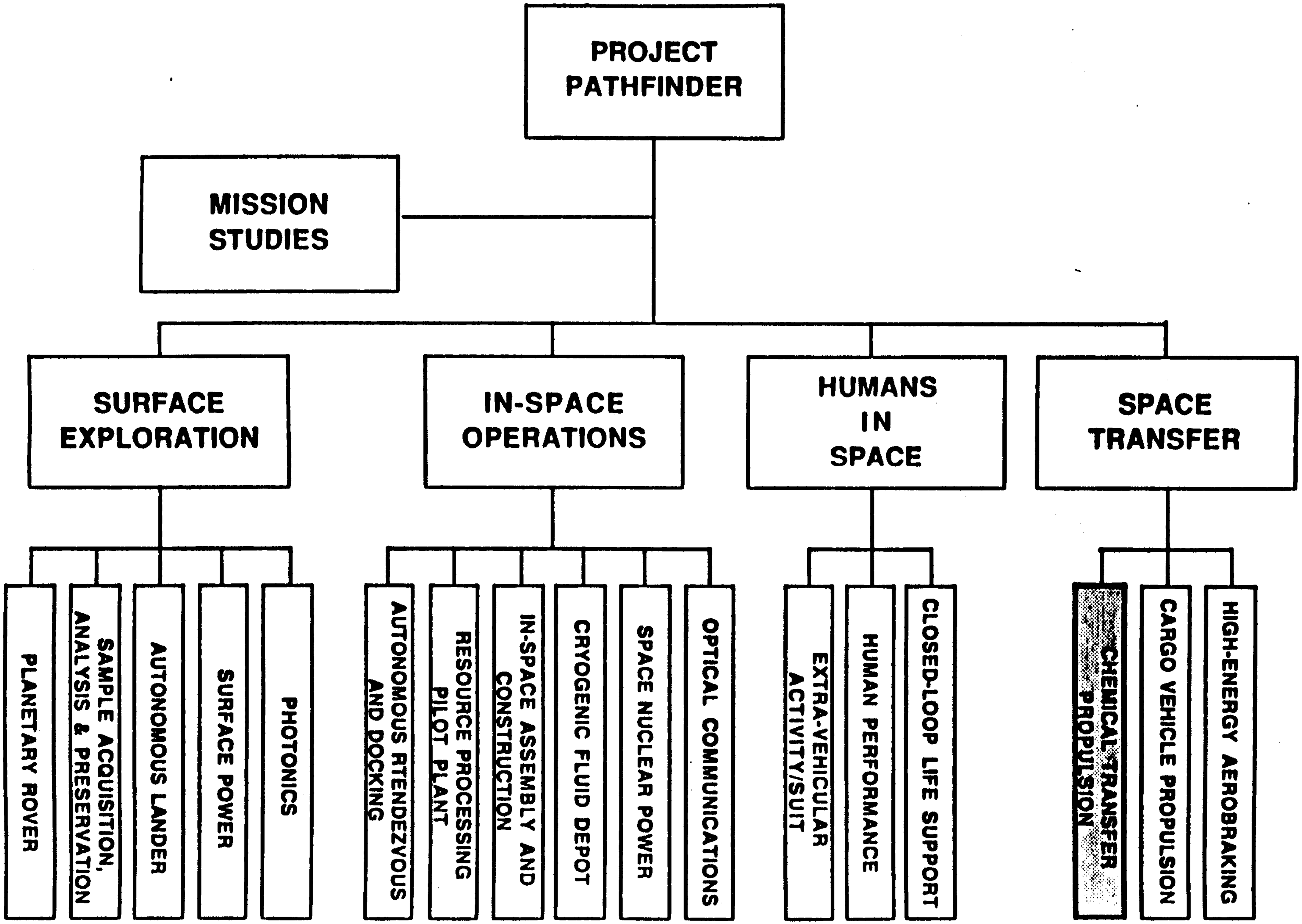

Figure 1: Project Pathfinder Work Breakdown Structure

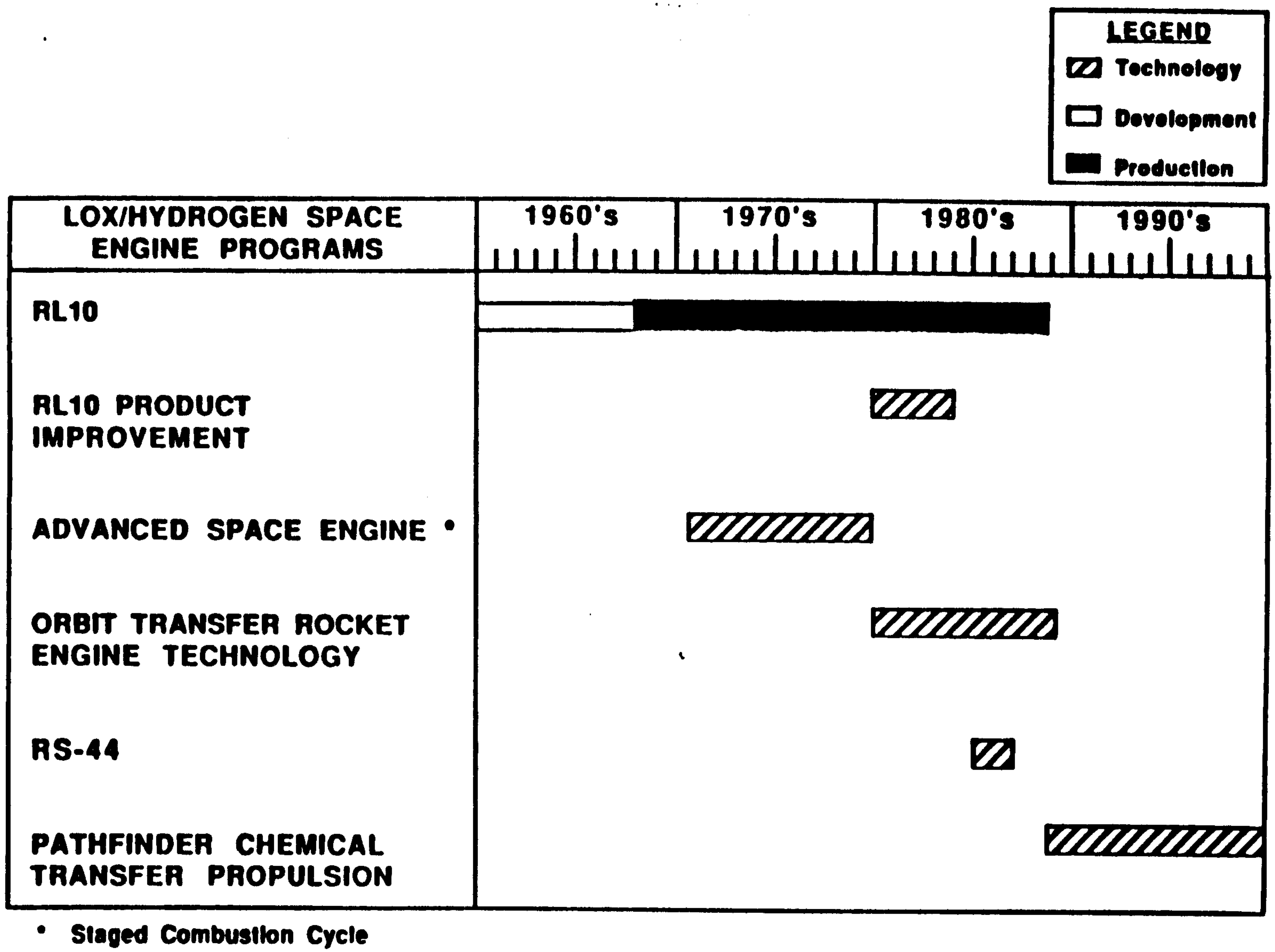

Figure 2: Liquid Oxygen/Liquid Hydrogen Upper Stage Engine History

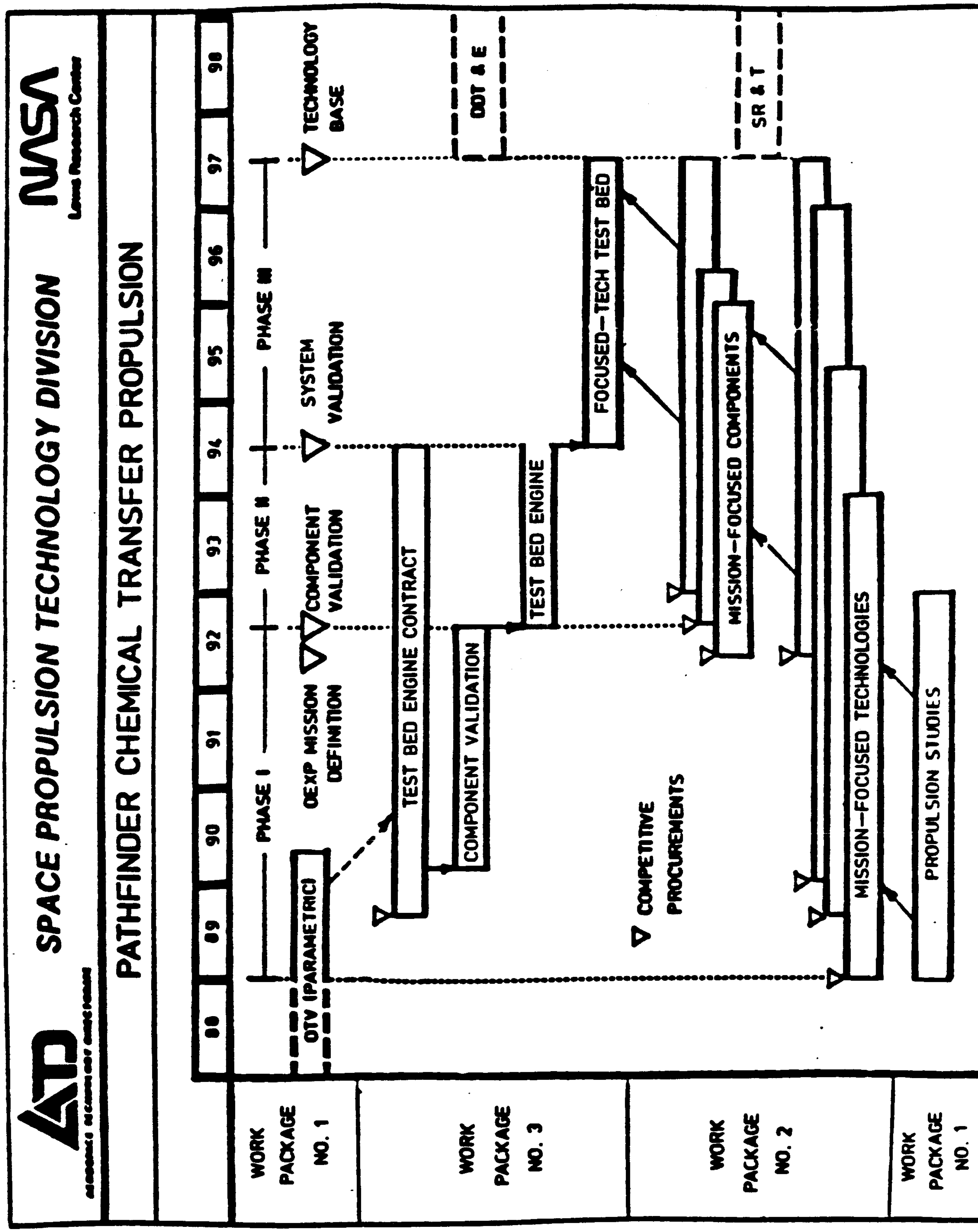

Figure 3: Chemical Transfer Propulsion Program Schedule

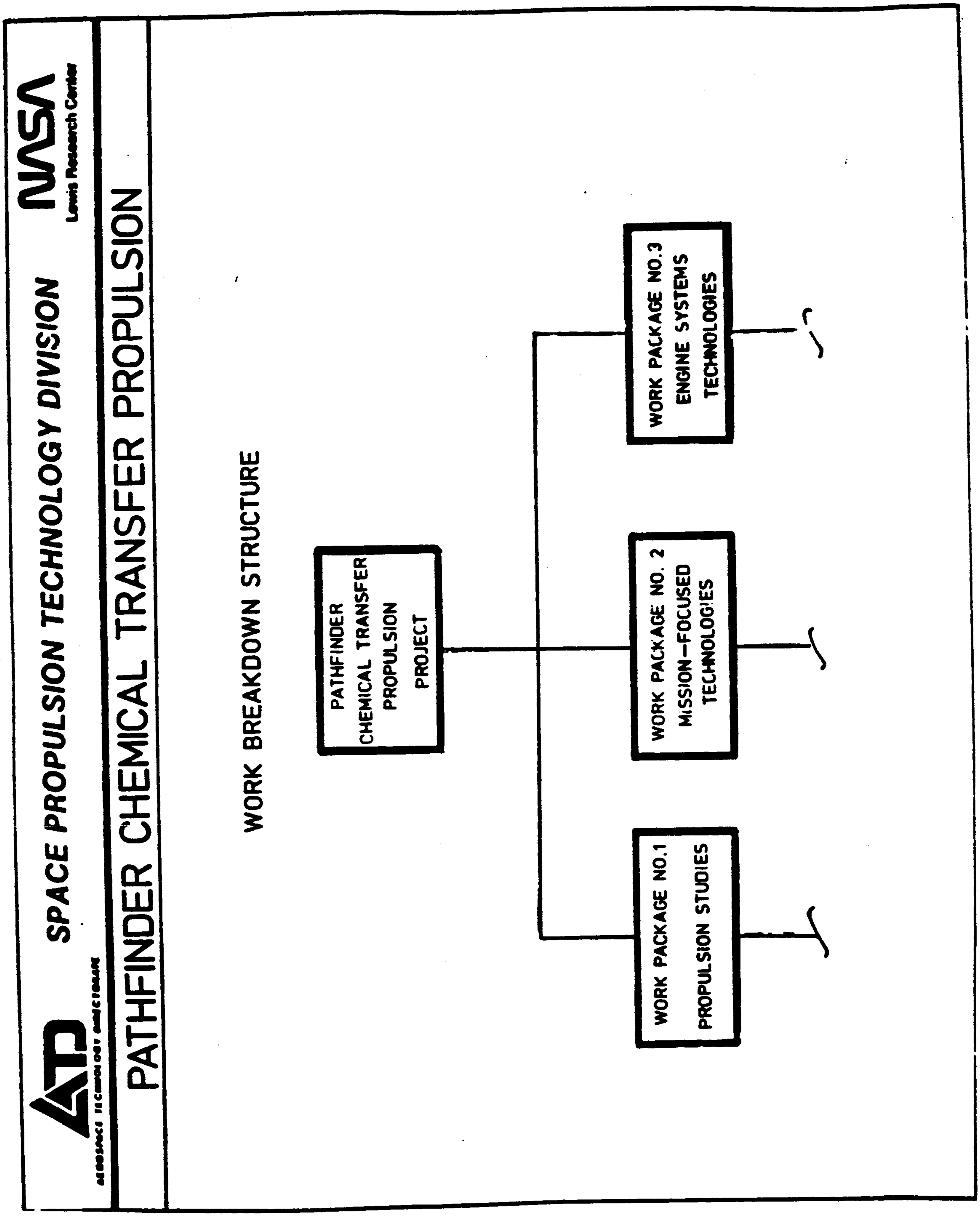

Figure 4: Chemical Transfer Propulsion Program Work Breakdown Structure

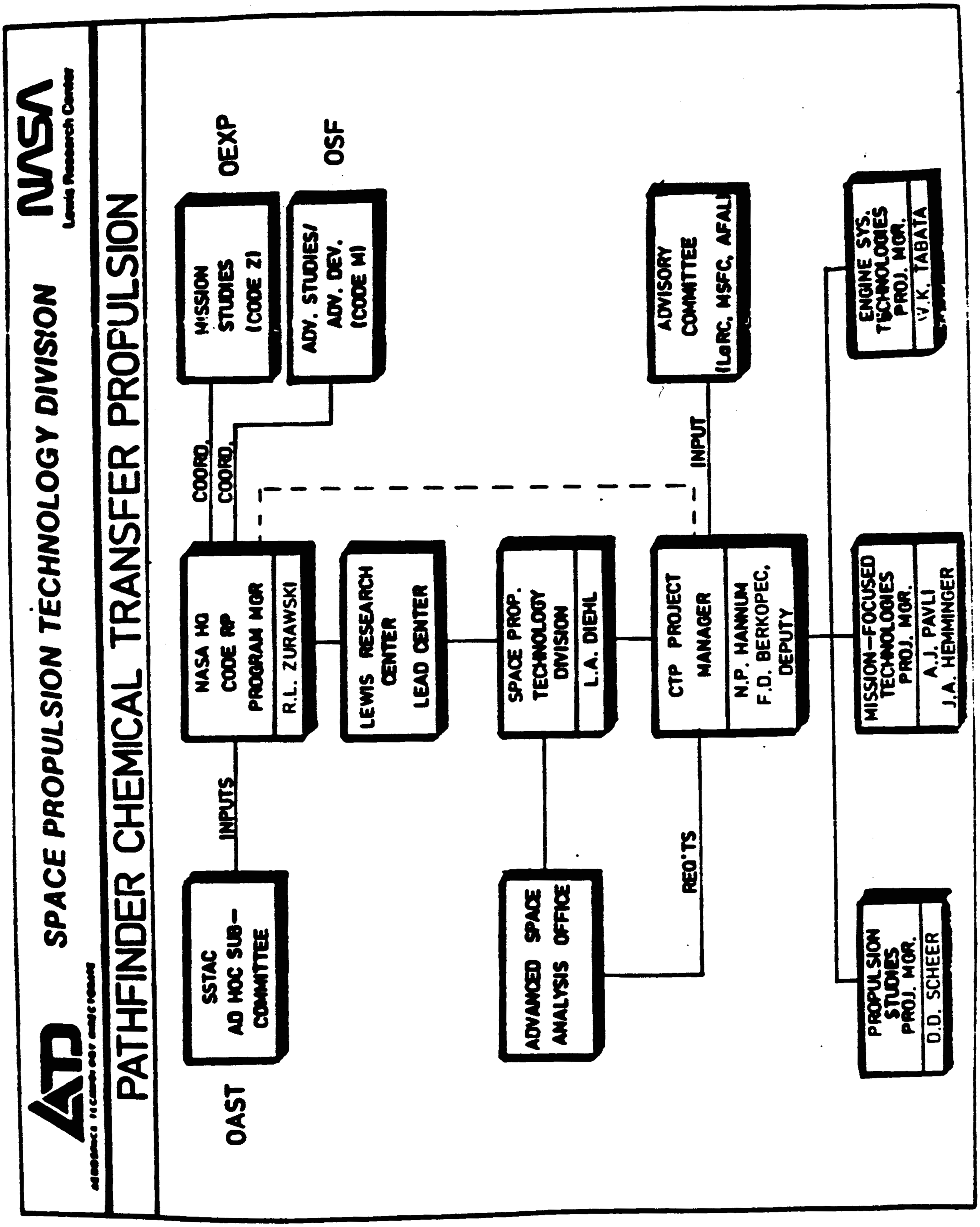

Figure 5: Chemical Transfer Propulsion Program Organization

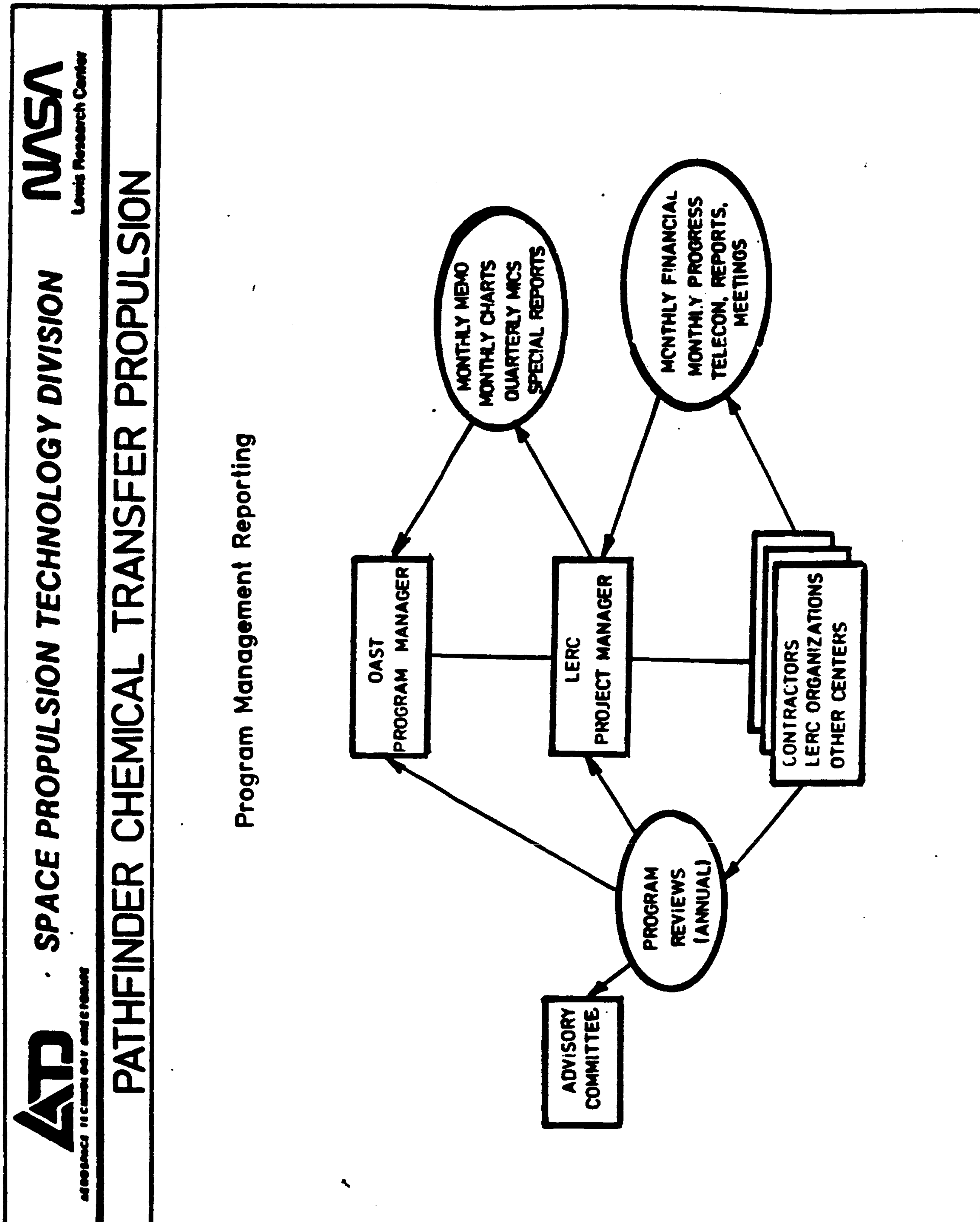

Figure 6: Program Management Reporting

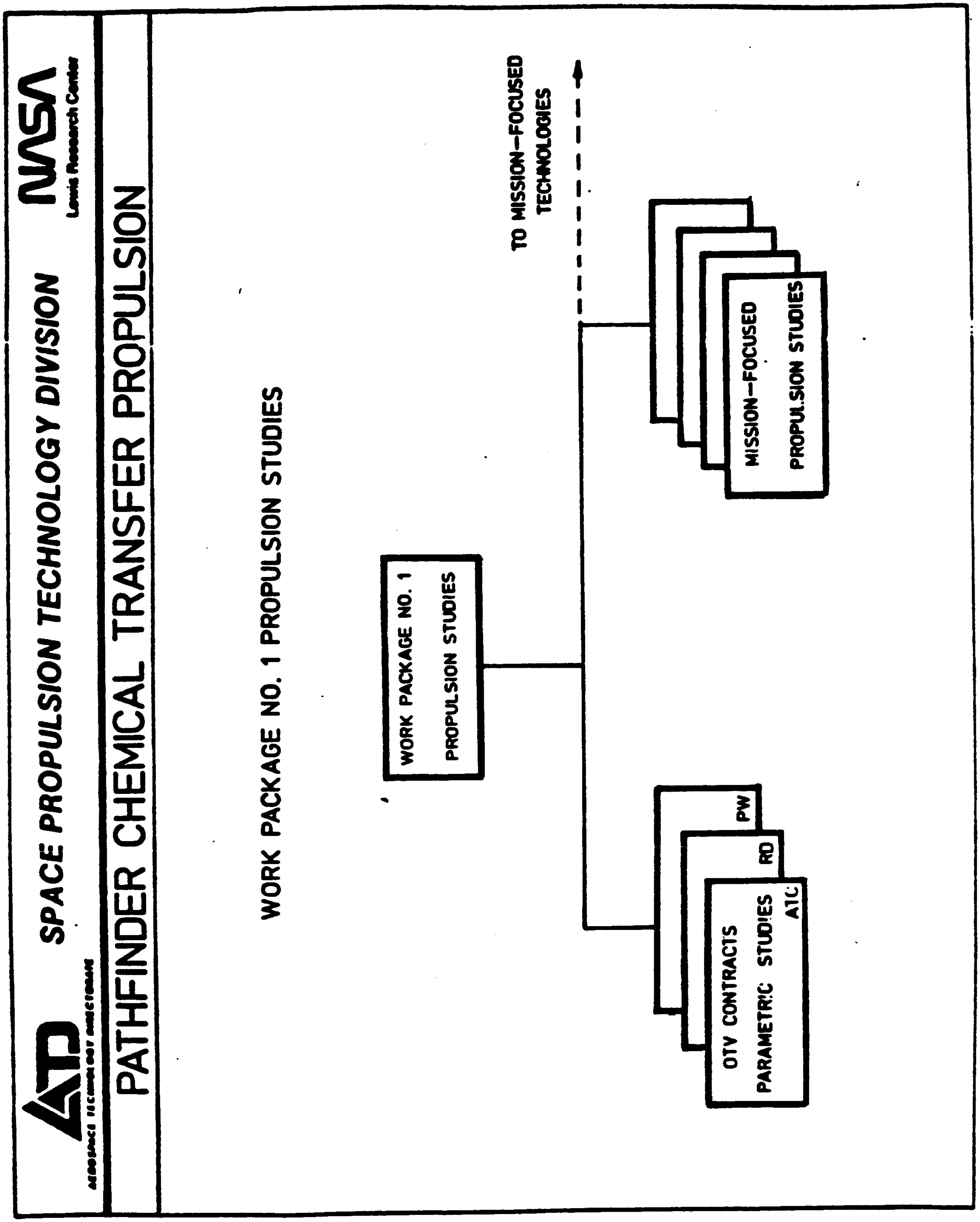

Figure 7: Work Package No.1 Work Breakdown Structure

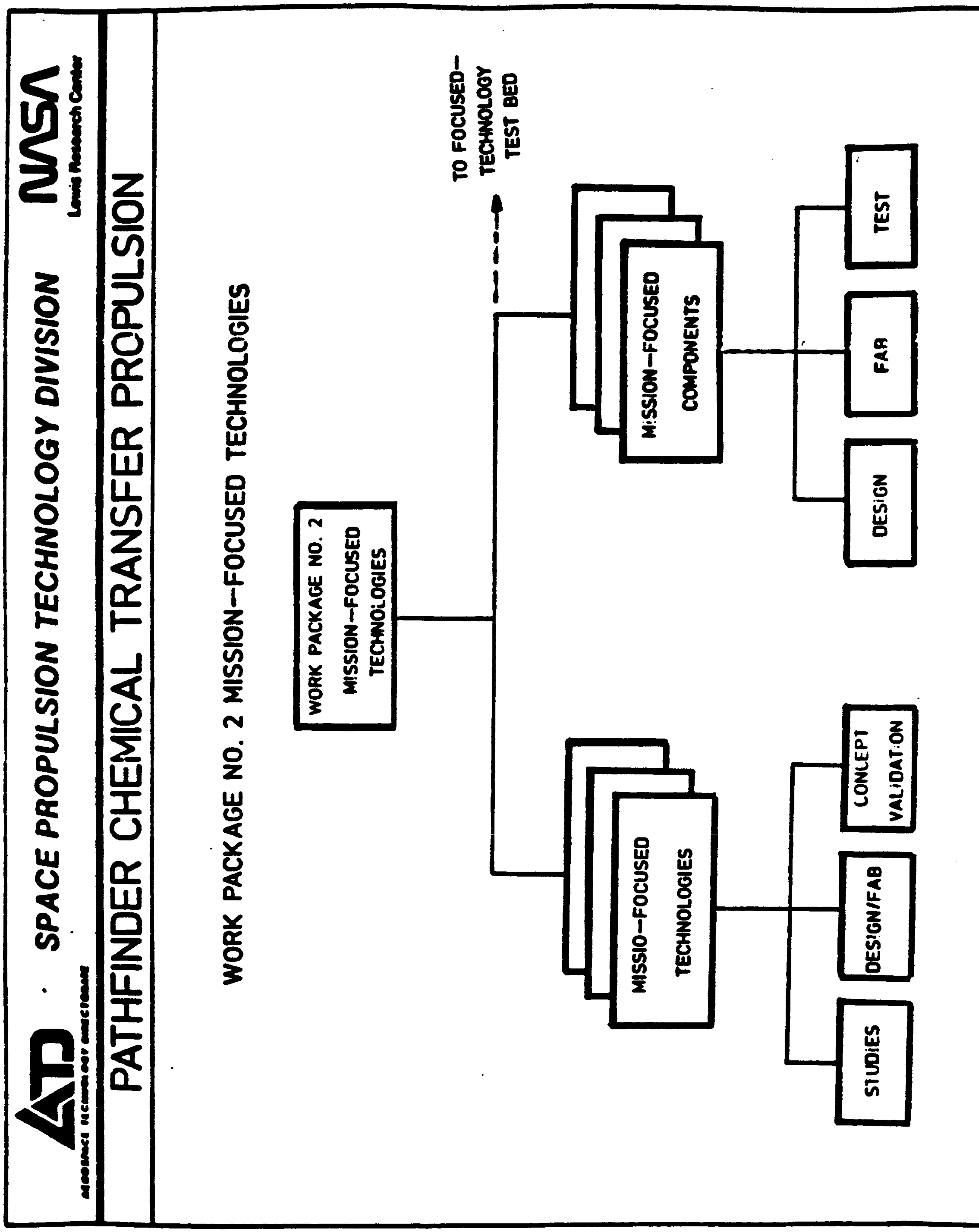

Figure 8: Work Package No.2 Work Breakdown Structure

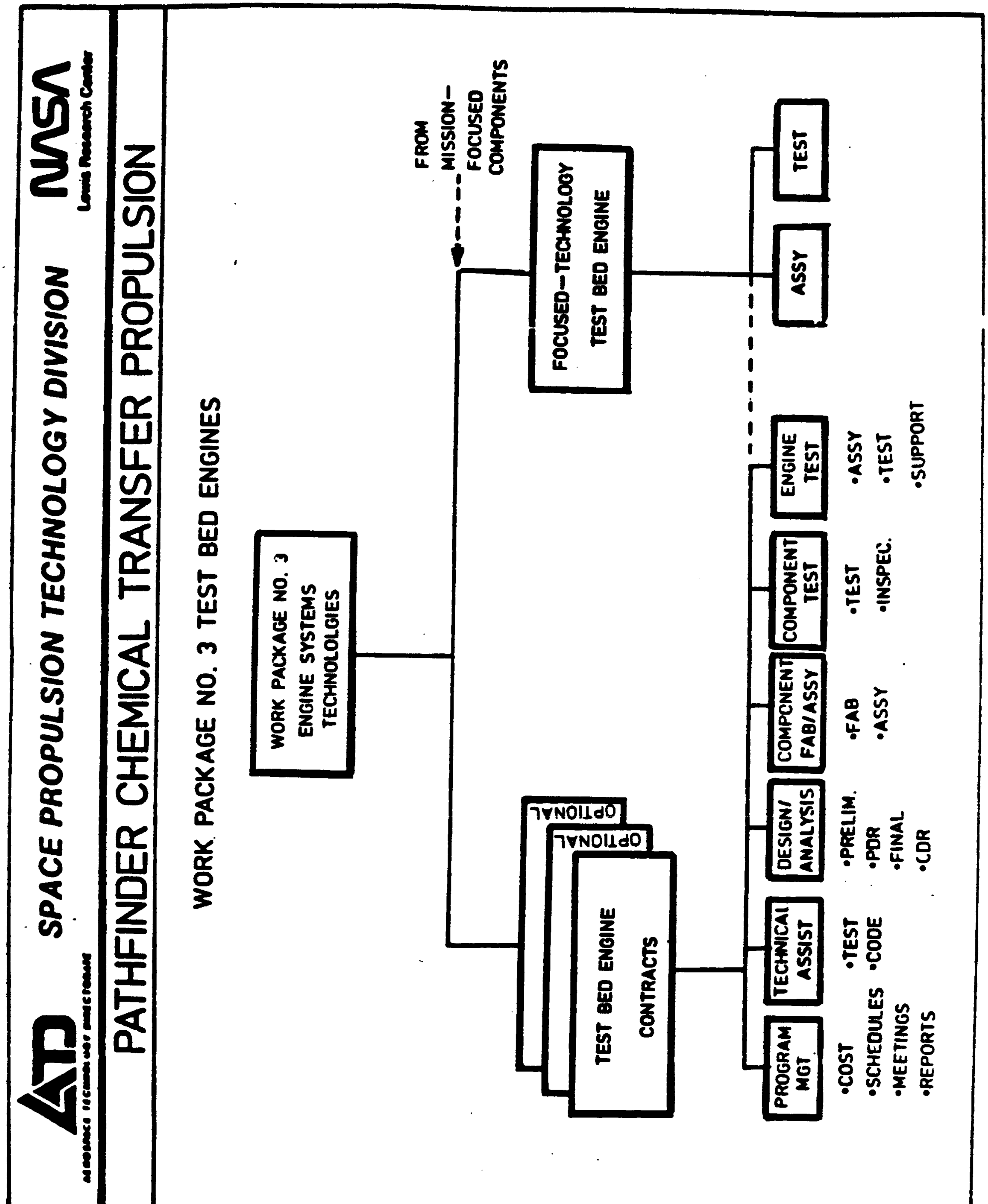

Figure 9: Work Package No.3 Work Breakdown Structure

11.0 TABLES

MISSION	THRUST	FUEL	ISP (SEC)	BURN TIME	REUSE	THROTTLEABLE	SPACE EXPOSURE
Mars Transfer (1st & 2nd stage)	75-100 K	LOX/LH2	> 460	< 30 min	Yes (10)	No	Months
Lunar Transfer Mars Transfer (3rd stage) Mars/Lunar Return	20-40 K	LOX/LH2	> 480	45-[illegible]0 min	Yes (10)	No	Years
Mars and Moon Descent	20-40 K	LOX/LH2	> 450	10-20 min	Mars-No Moon-Yes	Yes	Years
Mars and Moon Ascent	20-40 K	Note 1	Max	< 20 min	Mars-No Moon-Yes (10)	No	Years

Note 1: Must be compatable with surface heat loads and stay times and capability to reduce losses to mission acceptable levels

Table I: Chemical Transfer Propulsion Technology Requirements

Parameter	Reference Engine System (RL-10A-3-3A)	Space Transfer Vehicle Engine Technology Goals
Propellants - Fuel	Hydrogen	Hydrogen
Oxidizer	Oxygen	Oxygen
Power Cycle	Expander	Expander
Vacuum Thrust	16,500 lbf*	5 to 50 Klbf (Note 1)
Vacuum Thrust Throttling Ratio	Not Specified	20:1 (Note 2)
Vacuum Specific Impulse	444.4 lbf-sec/lbm	> 490 lbf-sec/lbm
Engine Mixture Ratio, O/F	5.0*	6.0 (Note 3)
Engine Mixture Ratio Range	4.4 to 5.[illegible]	5.0 to TBD (Note 4)
Combustion Pressure	465 psia*	> 1500 psia (Note 5)
Nozzle Area Ratio	61:1	1000:1
Weight	310 lbs	TBD
Length	70.1 in.	TBD
Life - Operational	3 starts, 4000 sec.	> 500 starts, 20 hours
Service Free	Not Specified	> 100 starts, 4 hours
Basing	Earth	Space
Human Rating	No	Yes
Design Criteria - Operational	Not Specified	Fault Tolerance
Aerobrake	None	Compatible with Aeroassist Transfer
Maintenance	Not Specified	In-Space Maintenance
Diagnostic Instrumentation	None	Integrated Controls and Health Monitoring

* - Design Point
TBD - To Be Determined
Note 1 - Thrust goal to be determined. Expected to be in 5,000 to 50,000 lbf thrust range.
Note 2 - Continuous and stable throttling from rated thrust to 5% thrust with minimum performance loss.
Note 3 - Mixture ratio goal to be determined. Performance goal specified at a mixture ratio of 6.0.
Note 4 - Engine mixture ratio range to be determined. Broad range desired for compatibility with fault tolerant engine operation and to potentially allow mixture ratio change during mission.
Note 5 - Chamber pressure must be compatible with performance and throttling goals.

Table II: Technology Goals for Space Transfer Engine

BASIC RESEARCH

FEASIBILITY RESEARCH

TECHNOLOGY DEVELOPMENT

TECHNOLOGY DEMONSTRATION

<u>LEVEL 1</u>	BASIC PRINCIPLES OBSERVED & REPORTED
<u>LEVEL 2</u>	TECHNOLOGY CONCEPT/APPLICATION FORMULATED
<u>LEVEL 3</u>	ANALYTICAL AND EXPERIMENTAL CRITICAL FUNCTION AND/OR CHARACTERISTIC PROOF-OF-CONCEPT
<u>LEVEL 4</u>	COMPONENT AND/OR BREADBOARD VALIDATION IN LABORATORY
<u>LEVEL 5</u>	COMPONENT AND/OR BREADBOARD DEMONSTRATION IN RELEVENT ENVIRONMENT
<u>LEVEL 6</u>	SYSTEM VALIDATION MODEL DEMONSTRATED IN SIMULATED ENVIRONMENT
<u>LEVEL 7</u>	SYSTEM VALIDATION MODEL DEMONSTRATED IN SPACE

TABLE III: Technology Readiness Levels

	FY 89	90	91	92	93	94	95	96	97	98
PROPULSION STUDIES										
• Engine Parametric Data Packages	△	△								
• Propulsion Trade Studies Complete				△						
• Propulsion System Requirements				△						
MISSION-FOCUSED TECHNOLOGIES										
• Technology Concepts/Applications Formulated		△								
• Engine Component Proof-of-Concept			△	△△△	△					
• Engine Component Validations in Test Bed Engine							△△	△△	△	
• Health Monitoring and Control Systems Defined								△		
• Design Criteria for In-Space Operation/Maintenance Validated								△		
• Component Design/Analysis Methodologies Verified									△	
ENGINE SYSTEMS TECHNOLOGIES										
• Test Bed Engine Contract Initiated	△									
• Design/Analysis Methodologies Assembled		△								
• Computer Simulations		△								
• Critical Design Reviews for Test Bed Engine		△								
• Test Bed Engine Component Tests Complete				△						
• Component Codes Validated				△						
• Test Bed Engine Assembled				△						
• Test Bed Engine Tests Complete						△				
• Focused—Tech Test Bed Assembled							△			
• Focused—Tech Test Bed Demonstration									△	
• Validated System Design/Analysis Technology Base									△	

Table IV: Chemical Transfer Propulsion Program Milestones/Deliverables

RESOURCES	SCHEDULE (FISCAL YEARS)				
	1989	1990	1991	1992	1993
FUNDING ($,M)	4.0	10.0	22.0	22.0	18.0
NASA WORKFORCE (WY/Y)	27.0	40.5	40.5	41.0	45.0

Table V: Chemical Transfer Propulsion Projected Resources